

1 **CLAIMS**

2 1. A method to estimate head motion between two images of a face, the  
3 method comprising operations of:

4 identifying locations of a plurality of distinct facial features in the two  
5 images, the locations corresponding to a number of unknowns determined upon  
6 estimation of head motion, the number of unknowns being determined by a  
7 number of equations;

8 converting the identified locations into a set of physical face parameters  
9 based on the symmetry of the distinct facial features, the set of physical face  
10 parameters reducing the number of unknowns as compared to the number of  
11 equations used to determine the unknowns; and

12 estimating head motion from identified points in the two images, the  
13 identified points being based on the set of physical face parameters.

14  
15 2. A method as recited in claim 1, wherein the operation of estimating  
16 head motion further comprises:

17 calculating an estimation objective function comprising a set of terms to  
18 estimate: (a) each of the set of physical face parameters, (b) a first head pose  
19 transform corresponding to the first image, and (c) a second head pose transform  
20 corresponding to the second image.

1           3.     A method as recited in claim 1, further comprising after the operation  
2 of converting and before the operation of estimating, an operation of:

3                 adding an inequality constraint on a particular face parameter of the  
4 physical face parameters, such that the particular face parameter is constrained  
5 within a predetermined minimum and maximum value.  
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7           4.     A method as recited in claim 3:  
8                 wherein the particular face parameter corresponds to the nose tip; and  
9                 wherein the predetermined minimum value is zero (0) and the  
10 predetermined maximum value is a reasonable value based on absolute values of  
11 other of the locations.  
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13           5.     A method as recited in claim 3, further comprising converting the  
14 inequality constraint to an equality constraint using a penalty function.  
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16           6.     A method as recited in claim 1, wherein the operation of estimating  
17 head motion further comprises operations of:

18                 calculating an estimation objective function to determine an initial estimate  
19 of head rotation, the estimation objective function comprising a set of terms to  
20 estimate: (a) each of the set of physical face parameters, (b) a first head pose  
21 transform corresponding to the first image, and (c) a second head pose transform  
22 corresponding to the second image;

23                 placing an inequality constraint on a particular face parameter of the set of  
24 physical face parameters, such that the particular face parameter is constrained  
25 within a predetermined minimum and maximum value;

1 converting the inequality constraint to an equality constraint using a penalty  
2 function; and

3 adding the equality constraint to the initial estimate [estimation system].  
4

5 **7.** A method as recited in claim 1, wherein the identified locations  
6 correspond to the eye corners, mouth corners and nose tip.  
7

8 **8.** A method as recited in claim 2, wherein in the operation of estimating  
9 the head motion further comprises an operation of multiplying each term of the  
10 estimation objective function by a weighted contribution factor based on the  
11 confidence of data corresponding to the estimation objective function.  
12

13 **9.** A method as recited in claim 5, wherein in the operation of providing  
14 further comprises operations of:

15 multiplying each term of the estimation objective function and the equality  
16 constraint by a weighted contribution factor based on the confidence of data  
17 corresponding to the estimation objective function.  
18

19 **10.** A method as recited in claim 1, wherein the identifying comprises  
20 accepting input from a human user.  
21

22 **11.** A computer-readable medium storing computer-executable  
23 instructions that, when executed on a computer, performs the method of claim 1.  
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1           **12.**   One or more computer-readable media containing a program that is  
2 executable by a computer to estimate motion between two images, the program  
3 comprising the following actions:

4           determining locations of a plurality of distinct features in the two images;  
5           converting the identified locations into a set of parameters based on the  
6 symmetry of the distinct features; and  
7           estimating motion between the two images based on the set of physical face  
8 parameters.

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10           **13.**   One or more computer-readable media as recited in claim 12,  
11 wherein the estimating motion further comprises:

12           calculating an estimation objective function comprising a set of terms to  
13 estimate: (a) each of the parameters, (b) a first transform corresponding to the first  
14 image, and (c) a second transform corresponding to the second image.

15  
16           **14.**   One or more computer-readable media as recited in claim 13,  
17 wherein in the estimating further comprises multiplying each term of the  
18 estimation objective function by a weighted contribution factor based on the  
19 confidence of data corresponding to the estimation objective function.

20  
21           **15.**   One or more computer-readable media as recited in claim 12, after  
22 converting and before estimating, further comprising:

23           adding an inequality constraint on a particular parameter of the parameters,  
24 such that the particular parameter is constrained within a predetermined minimum  
25 and maximum value.

1  
2       **16.**    One or more computer-readable media as recited in claim 15:  
3       wherein the predetermined minimum value and the predetermined  
4       maximum value are based on absolute values of other of the locations.

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6       **17.**    One or more computer-readable media as recited in claim 15, further  
7       comprising converting the inequality constraint to an equality constraint using a  
8       penalty function.

9  
10       **18.**   One or more computer-readable media as recited in claim 12,  
11       wherein the estimating further comprises:

12       calculating an estimation objective function to determine an initial estimate  
13       of image rotation, the estimation objective function comprising a set of terms to  
14       estimate: (a) each of the parameters, (b) a first pose transform corresponding to the  
15       first image, and (c) a second pose transform corresponding to the second image;

16       placing an inequality constraint on a particular parameter of the parameters,  
17       such that the particular parameter is constrained within a predetermined minimum  
18       and maximum value;

19       converting the inequality constraint to an equality constraint using a penalty  
20       function; and

21       adding the equality constraint to the initial estimate.  
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1       **19.** One or more computer-readable media as recited in claim 18,  
2 wherein in the calculating further comprises:

3       multiplying each term of the estimation objective function and the equality  
4 constraint by a weighted contribution factor based on the confidence of data  
5 corresponding to the estimation objective function.

6  
7       **20.** One or more computer-readable media as recited in claim 12,  
8 wherein the identifying comprises accepting input from a human user.

9  
10       **21.** A method to estimate head motion between two images of a face, the  
11 method comprising operations of:

12       identifying locations of a plurality of distinct facial features in the two  
13 images, the locations corresponding to a number of unknowns determined upon  
14 estimation of head motion, the number of unknowns being determined by a  
15 number of equations;

16       converting the locations into set of physical face parameters based on the  
17 symmetry of the identified distinct facial features, the set of physical face  
18 parameters reducing the number of unknowns as compared to the number of  
19 equations used to determine the unknowns;

20       determining an initial estimation of head motion between the two images  
21 using the set of physical face parameters; and

22       refining the estimation of head motion by incorporating the initial  
23 estimation into a feature matching algorithm.

1           **22.**    A method as recited in claim 21, wherein the identified locations  
2 correspond to the eye corners, mouth corners and nose tip.

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4           **23.**    A method as recited in claim 21, wherein the identifying comprises  
5 accepting input from a human user.

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7           **24.**    A method as recited in claim 21, further comprising multiplying the  
8 refined head motion estimate by a confidence factor that indicates that each of the  
9 identified locations was identified with a same level of accuracy.

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11          **25.**    A method as recited in claim 21, wherein determining an initial  
12 estimate of head motion comprises calculating an estimation objective function  
13 comprising a number of terms to estimate each of: (a) the set of coordinates, (b) a  
14 first head pose transform corresponding to the first image, and (c) a second head  
15 pose transform corresponding to the second image.

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17          **26.**    A method as recited in claim 25, wherein in the operation of  
18 determining further comprises multiplying each term of the estimation objective  
19 function by a weighted contribution factor based on the confidence of data  
20 corresponding to the estimation objective function.

1       **27.**    A method as recited in claim 21, after the converting and before the  
2 determining, further comprising:

3            adding an inequality constraint on a particular parameter of the physical  
4 face parameters, such that the parameter is constrained within a predetermined  
5 minimum and maximum value.

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7       **28.**    A method as recited in claim 27:

8            wherein the particular parameter corresponds to the nose tip; and

9            wherein the predetermined minimum value is zero (0) and the  
10 predetermined maximum value is a reasonable value based on absolute values of  
11 other of the locations.

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14       **29.**    A method as recited in claim 27, further comprising converting the  
15 inequality constraint to an equality constraint using a penalty function.

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17       **30.**    A method as recited in claim 21, wherein the determining further  
18 comprises:

19            calculating an estimation objective function to comprising a set of terms to  
20 estimate each of: (a) the physical face parameters, (b) a first head pose transform  
21 corresponding to the first image, and (c) a second head pose transform  
22 corresponding to the second image;

23            adding an inequality constraint on a particular parameter of the physical  
24 face parameters, such that the particular parameter is constrained within a  
25 predetermined minimum and maximum value;



1 converting the inequality constraint to an equality constraint using a penalty  
2 function; and  
3 adding the equality constraint to the initial estimate.  
4

5 **31.** A method as recited in claim 30, wherein in the operation of  
6 providing further comprises operations of:

7 multiplying each term of the estimation objective function and the equality  
8 constraint by a weighted contribution factor based on the confidence of data  
9 corresponding to the estimation objective function.  
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11 **32.** A computer-readable medium storing computer-executable  
12 instructions that, when executed on a computer, performs the method of claim 21.  
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14 **33.** A method to estimate motion between two images, the method  
15 comprising operations of:

16 identifying locations of a plurality of distinct features in the two images, the  
17 locations corresponding to symmetrical features shared between the two images,  
18 the locations corresponding to a number of unknowns determined upon estimation  
19 of motion between the two images;

20 converting the locations into a set of parameters based on the symmetry of  
21 the identified distinct features, the parameters reducing the number of unknowns  
22 as compared to a number of equations used to determine the unknowns; and

23 estimating motion between the two images using the parameters.  
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1           **34.**    A method as recited in claim 33, wherein the estimating further  
2 comprises:

3           providing an initial estimate of image rotation by estimation of each of the  
4 parameters, a first image pose transform corresponding to the first image, and a  
5 second image pose transform corresponding to the second image;

6           adding an inequality constraint on a particular parameter of the parameters,  
7 such that the particular parameter is constrained within a predetermined minimum  
8 and maximum value;

9           converting the inequality constraint to an equality constraint using a penalty  
10 function; and

11          adding the equality constraint to the initial estimate.  
12

13           **35.**    A method as recited in claim 33, wherein the estimating further  
14 comprises calculating an estimation objective function comprising a number of  
15 terms to estimate each of: (a) the parameters, (b) a first image pose transform  
16 corresponding to the first image, and (c) a second image pose transform  
17 corresponding to the second image.  
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20           **36.**    A method as recited in claim 35, wherein in the operation of  
21 providing further comprises an operation of multiplying each term of the  
22 estimation objective function by a weighted contribution factor based on the  
23 confidence of that corresponding data.  
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1           **37.**    A method as recited in claim 33, after the converting and before the  
2 estimating further comprising:

3           adding an inequality constraint on a particular parameter of the physical  
4 face parameters, such that the particular parameter is constrained within a  
5 predetermined minimum and maximum value.

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7           **38.**    A method as recited in claim 37, further comprising converting the  
8 inequality constraint to an equality constraint using a penalty function.

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10          **39.**    A method as recited in claim 34, further comprising:  
11          multiplying each term of a set of terms used to determine the initial estimate  
12 by a weighted contribution factor based on the confidence of data corresponding to  
13 the initial estimate.

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15          **40.**    A computer-readable medium storing computer-executable  
16 instructions that, when executed on a computer, performs the method of claim 33.

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18          **41.**    A method comprising:  
19          identifying locations of a plurality of distinct features in two images, the  
20 locations corresponding to symmetrical features shared between the two images,  
21 the locations being identified in a first coordinate system;  
22          converting the locations into a second coordinate system that is based on the  
23 symmetry of the identified distinct features, the locations being described by a set  
24 of coordinates in the second coordinate system; and  
25

1       determining a motion estimate between the two images using the set of  
2 coordinates.

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4       **42.**   A computer-readable medium storing computer-executable  
5 instructions that, when executed on a computer, performs the method of claim 41.  
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